

SATELLITE ALTIMETER MEASUREMENTS OF SURFACE WIND

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In the present work, geophysical model functions (GMFs) for altimeter wind speed measurements are described. These GMFs account for an effect of [the actual degree of sea development on the radar cross section by utilizing information on the significant wave height. The wind speed measurement accuracy achieved (the overall bias 0.1 m/s and the rms error about 1.6 m/s) is higher than the accuracy of commonly employed GMFs while the wave-age-related trend is reduced to a geophysically insignificant level.

1. Introduction

In recent years the influence of sea maturity on satellite measurements received considerable attention: satellite scatterometer, altimeter and microwave radiometer measurements of surface winds were re-examined (this work is reviewed in [Glazman, 1991]) and the sea state bias was investigated based on Geosat altimeter data [Fu and Glazman, 1991]. These studies revealed the existence of an error trend which is related to the sea maturity and is present, to a greater or smaller degree, in all satellite microwave measurements. In this report (based on [Glazman and Greysukh, 1993] thereafter referred to as G&G), we propose new geophysical model functions (GMFs) which greatly reduce this error trend and improve the overall accuracy of wind speed measurements.

The rms ("standard") error of satellite measurements is the most commonly used characteristic of the measuring accuracy. However, other characteristics may also be important. For instance, if the wind speed measurements are used to prepare maps of wind stress over the ocean, the absolute mean error becomes highly important. Indeed, the wind stress is usually determined as $\tau = C_D U^2$ where C_D is the drag coefficient. The satellite-reported wind U_S contains random error, e : $U_S = U_{true} + e$. Therefore, the wind stress is

$$\tau = C_D (U_{true}^2 + 2eU_{true} + e^2) \quad (1)$$

Both the rms error $\langle e^2 \rangle^{1/2}$ and the mean absolute error $\langle e \rangle$ contribute to an error in the estimated wind stress. (The angular brackets denote averaging of the data within appropriate bins.) Equation (1) allows one to formulate the requirements to the accuracy of wind speed measurements in terms of the mean error $\langle e \rangle$. Suppose the lowest rms error achievable by satellite measurements is 1.7 m/s. We shall demand that the mean error $\langle e \rangle$ remain near or below $\langle e^2 \rangle^{1/2} / 2U$, which limits the contribution of the second term in the r.h.s. of (1) to that of the third term. Take $U_{true} \approx 7$ m/s and $\langle e^2 \rangle^{1/2} \approx 1.7$ m/s. Apparently, in order to neglect the contribution of the second term in the r.h.s. of (1) compared to that of the third term, condition $\langle e \rangle \ll 0.2$ m/s must hold. Thus, a requirement that the mean error, $\langle e \rangle$, be below 0.2 m/s can be viewed as a criterion of applicability of altimeter (as well as other instruments) wind speeds as input to wind-driven cumulation models.

We can also impose a limit on the wave-age related trend in wind measuring errors. Suppose, this trend can be crudely

quantified by a linear function: $c = C_0 + C_1 \xi$ where ξ is the (pseudo) wave age and C_1 is the "trend coefficient" in m/sec per unit ξ . The pseudo wave age is determined as $\xi = A(gH/U^2)^v$ where H is the significant wave height, g is the acceleration of gravity, and A and v are empirical constants given, e.g., by Glazman and Pilorz [1990]. Evidently, limiting the value of C_1 to 0.5 m/s per unit ξ reduces this false trend to the level which is well below the random error, while a value of C_1 as high as 1 m/s makes this trend to be prominent even on the random noise background.

A collocated set of autonomous buoy (of the National Data Buoy Center) and Geosat altimeter measurements for the period November 1986 through July 1989 was compiled at JPL from Geosat GDR and NDBC data and used in the data analysis. This data set is presently available to the science community through the JPL Physical Oceanography Distributed Active Archive Center. The data, the experimental procedure and the results are explained in great detail by G&G.

2. Altimeter wind speed measurements

According to Dobson et al. [1987], the most accurate GMF for altimeter wind speed is due to Brown et al. [1981]. Like other known GMFs, it relates the radar cross section σ_0 to the mean wind U at 10 m height. Earlier [Glazman and Pilorz, 1990], the actual relationship between U and σ_0 was found to be ambiguous: at a given wind speed, the observed σ_0 may vary depending on the wave age, ξ . In Table 1 we show the trend coefficient C_1 and other characteristics of the Brown GMF. Evidently, the wave-age related error trend is too high.

We compared the Brown GMF to the most recent GMF proposed by Witter and Chelton [1991]. The latter represents a modification of the Chelton-Wentz tabular GMF [Chelton and Wentz, 1986], hence is called the Modified Chelton-Wentz (MCW) function. When MCW was applied to our data set, it was found to produce it very low wave-age trend: $C_1 \approx 0.35$ m/s per unit ξ . This feature would make MCW highly useful. Unfortunately, its other characteristics, as listed in Table 1, are less favorable: the mean bias, $\langle e \rangle = 0.44$ m/s, is considerably worse than that of the Brown GMF. In view of our earlier comments related to eq (1), we conclude that the presently available GMFs need improvement.

Apparently, in order to improve altimeter wind speed measurements in the sense of all the parameters employed in Table 1, it is not sufficient to use the radar cross section alone. As mentioned earlier, the pseudo wave age ξ can be estimated based on H and U ; and since ξ influences the radar cross section, an empirical GMF can be sought as a function of two variables

$$U = F(\sigma_0, H) \quad (2)$$

A continuous function $F(\sigma_0, H)$ based on Chebyshev polynomials was developed by G&G, and its performance is

summarized in Table 1. Evidently, the wave-age related trend is still too large. The main difficulty with functions (2) is the additional error noise caused by measuring errors in H . The detrimental effect of the measurement noise in the variables σ_0 and H can be reduced by recognizing the fact that a continuous function approach is inherently flawed when one of the factors (SWH) has a relatively small influence on σ_0 .

Reviewing the physical mechanism responsible for the effect of ξ on the radar cross section [Glazman, 1990; Glazman and Pilorz, 1990], a classifier-based approach appears more promising. It is based on breaking all observations down into subsets corresponding to different regimes in the sea surface's geometry (quantified by limited sub-ranges of ξ), and then determining an individual relationship $U = F_j(\sigma_0)$ for each range, j , of ξ . The simplest version of this approach is implemented by identifying just two subsets separated by a critical wave age, ξ_{cr} . Then in the first approximation, the effect of H could be taken into account as a factor influencing the separation of the data into the subsets: $j=1$ or $j=2$. In the absence of auxiliary information on the degree of wave development, the determination of the appropriate gradation of wave age is a difficult problem. Two empirical classifiers which solve this problem are developed by G&G. The accuracy of these GMFs is reported in Table 1.

3. Wind speed histograms

It has been noted [Dobson et al., 1987] that the Brown algorithm [Brown et al., 1981], regardless of its low mts error, results in distortions of wind speed histograms if the wind speed gradations are narrow. To rectify the problem, a "smooth Brown" GMF was suggested in the form of its fifth degree polynomial: $U = \sum a_n \sigma_0^n$ which approximates the original Brown algorithm [Dobson et al., 1987] in the range $8 \text{ dB} < \sigma_0 < 15 \text{ dB}$. Within the corresponding wind speed interval, 1.54 to 15 m/s, the smooth GMF is claimed to have an advantage over the original Brown GMF, for it yields unimodal wind histograms whereas the original Brown GMF may produce false peaks.

Actually, all presently available GMFs yield singularities at some point (or points) and distort the histograms to a greater or lower degree. The MCW function discussed in section 2 has singularities at all points for which it is given in the tabular form because this GMF involves a linear interpolation between the points, hence it has discontinuous $d\sigma_0/dU$ at each such point. The classifier-based GMF developed in the present work would also yield singularities because it involves branching. Hence, the question arises as to whether and how one should use these algorithms for wind speed statistics.

The short answer is: all algorithms mentioned above, including the original Brown and the tabular GMFs, can be used in statistical problems. However, the choice of a specific GMF depends on the problem at hand. If the wind speed gradations were arbitrarily narrow, a GMF would have to possess continuous derivatives. In practice, the gradations have finite width. Hence, by an appropriate adjustment of wind speed gradations, the impact of singularities and branching can be controlled or eliminated. Examples presented in G&G confirm this assertion.

4. Conclusions

The present work indicates that there exists a potential for further improvement of the accuracy of altimeter measurements.

The increased accuracy of the wind speed determination achieved by the wave-age-dependent algorithms makes it theoretically possible to further improve estimates of the sea state bias for sea level measurements, for example following the procedure suggested in [Fu and Glazman, 1991] and [Glazman et al., 1993].

The use of only two gradations of the wave age was dictated here by the relatively small amount of data available for analysis. New satellite missions, ERS-1 and TOPEX, will

eventually yield more accurate and voluminous data, which will enable one to carry out a more detailed stratification of the wave age gradations, leading to more accurate wind speed and sea state bias algorithms.

The classifier-based GMFs can be successfully used for constructing histograms of wind speed distribution. However, we recommend that the width of wind speed gradations for such analyses be greater than 1 m/s.

ACKNOWLEDGMENTS: This work was performed at the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration.

Table 1: Characteristics of GMFs

Wind speed GMF	mean error $\langle e \rangle$ (m/s)	rms error $\langle e^2 \rangle^{1/2}$ (m/s)	3rd moment $\langle e^3 \rangle$ (m/s) ³	skwns γ	error trend CI (M/s)
Brown	0.17	1.69	0.63	0.13	1.01
Brn smooth	-0.06	1.70	-2.21	-0.45	1.01
MCW	0.44	1.70	0.64	0.13	0.35
Continuous	-0.04	1.63	0.48	0.11	0.81
Classifier I	0.01	1.70	-0.10	-0.02	0.43
Classifier II	0.11	1.63	0.13	0.03	0.50

Notations used in Table 1: Error, e , of wind speed measurements by altimeter is defined as: $e = U_S - U_B$ (m/s). The angular brackets " $\langle \dots \rangle$ " denote averaging over the data set. The skewness, γ , of the error distribution is $\langle e^3 \rangle / \langle e^2 \rangle^{3/2}$. The error trend is defined as the coefficient CI (M/s) in the linear regression model: $e = C_0 + C_1 \xi$ for the range $0 < \xi < 4$, and ξ is estimated based on eq.(1.3) using buoy data. "Brown" stands for the GMF developed by Brown et al. [1981], "Brn smooth" stands for a polynomial fit to "Brown" described by [Dobson, et al., 1987]. "Continuous (2)" means the Chebyshev polynomial approximation for (2) reported by G&G, "Classifier I" and "Classifier II" denote the classifier-based approach using two types of demarcation curves as described in G&G.

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